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VIBRATION ANALYSIS OF HONEYCOMB SANDWICH PANEL IN SPACECRAFT STRUCTURE

M. MARYTHRAZA[1], D. ANITHA[2], P. K. DASH[3] & P. RAVI KUMAR[4]

[1,2,4]Assistant Professor, Department of Aeronautical Engineering, Institute of Aeronautical Engineering, Hyderabad, Telangana, India

[3]Professor, Department of Aeronautical Engineering, MLRIT, Hyderabad, Telangana, India

ABSTRACT

A Spacecraft structure has a cuboid construction and is composed of central cylinder and a number of interconnected honeycomb sandwich panels. A spacecraft structure accommodates all electronic packages and provides adequate strength and stiffness to withstand the launch loads. A honeycomb sandwich panel is made up of aluminum honeycomb core joined with aluminium face sheets using adhesive. A spacecraft experiences various types of loads during its launch such as vibration, acoustic and shock loads. The spacecraft structure is designed to withstand the launch vibration environment. It is essential to perform dynamic analyses to obtain the dynamic characteristics of the panel like natural frequencies, mode shapes and acceleration responses at different locations. The present work involves normal modes and transient analyses of honeycomb sandwich panels. The objective of this project is to predict the vibration response of honeycomb sandwich panels due to dynamic loads. The modal analysis, transient response analysis of the honeycomb sandwich panel has been done by using Msc Nastran/Patran and the natural frequency from the simulation results compared with the analytical results.

KEYWORDS: Sandwich Construction, Pyroshock, Modal Analysis & Transient Response Analysis

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Original Article

INTRODUCTION

Spacecraft Structure

A spacecraft structure has a cuboid construction that composed of large number of sandwich panels surrounded by the central cylinder. Spacecraft structures are mainly divided into two categories. The primary structure also known as main structure whose purpose is to transfer the loads to base of the satellite through design components. The design components are bartruss, honeycomb platform, central tube etc. This structure provides the attachment points for the payload. If any failure occurs in the primary structure the entire system will be collapsed.

The secondary structures includes baffle, thermal blanket support and solar panel which they are support themselves and are attached to the primary structure which gives the overall structural integrity. But the secondary structure failure is not a problem for the structural integrity.

Considering the new generation large satellites the spacecraft structure must consider the third type structure which is flexible appendages. The flexible append ages such as antenna reflectors and solar arrays. These structures are having low resonant frequencies which interact directly on the dynamic behaviour on the satellite and it must require special care of design.

A Spacecraft structure undergoes various kinds of load during the launching environments. The structure should cater to the various requirements. First of all, it must resist the loads created by the launch environments (acceleration, acoustics thermal). Figure 1 shows the honeycomb sandwich panels mounted on the spacecraft structure.

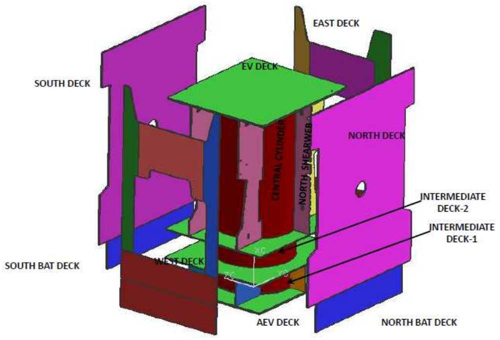

Figure 1: Spacecraft Structure

- **Sandwich Construction**

Spacecraft structure interconnected with large number of sandwich panels. The sandwich panels are widely used in the spacecraft structure due to its high stiffness and strength to weight ratio. There are several methods to enhance structural properties of the spacecraft structure. The suitable method is to vary the design task. One of the widely used methods is sandwich structure. Figure 2 shows the sandwich construction.

Sandwich construction is used in skin frame designs and solar panels. A Sandwich structure consists of two thin face sheets and one light weight core structure. The face sheets are adhesively bonded with both side of the core. The outer face sheets can carry axial loads, bending moments, and in-plane shears while core carries normal flexural shears. The modulus of the operandi of the sandwich structure is the same as that of I beam section which is efficient structural shape because as much as possible material placed in the flanges which is far from the centre of bending or neutral axis. Only enough material is left connecting the web to make the flanges work together and to resist the shear and buckling. Considering the above criteria in sandwich panel, the face sheet act as the flanges and the core act as web. In the core materials the honeycomb type developed and primarily used in the aerospace applications. The honeycomb materials can be manufactured in variety of cell shapes. But hexagonal cell shape materials mostly used. Aluminium 5052, 5056, 2024 materials extensively used for aerospace applications during past decades. In the face sheet metallic and non metallic materials can be used. The metallic materials include the steel, stainless steel, aluminium alloys can be used and non-metallic materials are fiber composite materials. In this paper the core and face sheet materials will be aluminium.

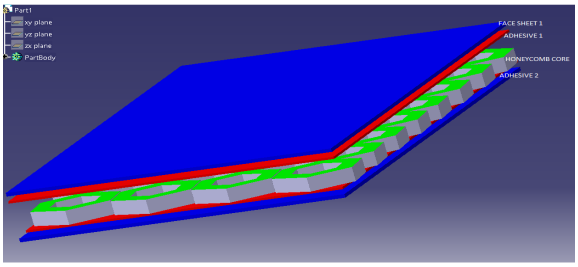

Figure 2:Sandwich Construction

- **Pyroshock**

The aerospace industry was first recognizing the potentially destructive effect of pyroshock. The firing of explosive bolts, pins, nuts, and cutters initiated the pyroshock. Pyrotechnic devices are commonly used in space applications. Pyroshocks occur due to controlled explosion of pyrotechnic devices enabling the functionality of space modules such as deployment of appendages. The detonation of the pyrotechnic devices produces high frequency transient forces on the spacecraft structure. Pyroshocks can cause failure of electronic devices and equipment. The transient response prediction of honeycomb panel is important from the design and reliability point of view. Pyroshock or pyrotechnic shock is the dynamic structural shock that occurs when explosion or impacts occurs on the spacecraft structure. Pyroshock is the decaying, oscillatory response of a structure to high-amplitude and high frequency excitation. The frequencies that comprise this oscillatory response can extend to thousands of hertz.

PROBLEM IDENTIFICATION

A spacecraft experiences various types of loads during its launch such as vibration, acoustic and shock loads. Especially the pyroshock occurs on the spacecraft structure, due to that the sudden impact load occurs on the spacecraft structure. The spacecraft structure is designed to withstand the launch vibration environment.

METHODOLOGY

- Development of Finite Elemental model of a honeycomb sandwich panel using PATRAN/MSC NASTRAN.
- Performing modal analysis and transient response analysis for various boundary conditions.
- Performing various case studies and parametric studies for different boundary conditions and dynamic loads.
- Comparing the Analytical solution with the results from FE model.

ANALYTICAL SOLUTIONS FOR HONEYCOMB SANDWICH PANEL (MODAL ANALYSIS)

Based upon the requirements the dimensions and properties of the honeycomb sandwich panel selected. The honeycomb sandwich panel is thin and symmetric.

Table 1: Dimensions of the Sandwich Panel

S/No	Specifications	Dimensions
1	Length of the panel	1.35 meters
2	Breath of the panel	1 meters
3	Thickness of the face sheet	0.25×10^{-3} meters
4	Thickness of the core	25×10^{-3} meters

Table 2: Properties of the Sandwich Panel

S/No	Specifications	Values
1	Elastic modulus of the face sheet	70×10^{9} N/m^2
2	Elastic modulus of the core	1.004×10^{4} N/m^2
3	Shear modulus of the core	1.4×10^{8} N/m^2
4	Poisson ratio	0.33
5	Density of the face sheet	2700 kg/m^3
6	Density of the core	32 kg/m^3

- **Flexural Rigidity of Sandwich Panel**

The expression of flexural rigidity for symmetrical sandwich plate will be

$$D=\int Ez^2=\frac{E_f t_f^3}{6}+\frac{E_f t_f d^2}{2}+\frac{E_c t_c^3}{12}$$

D=5578.79 N-m

- **Density**

The expression for density i.e. the cross sectional properties

$\rho^* = \rho_1 t_1 + \rho_c t_c + \rho_2 t_2$

$\boldsymbol{\rho^*=2.15\ kg/m^2}$

- **The Natural Frequency of the Clamped Isotropic Sandwich Plate**

$$f_n=\frac{\pi}{1.5}\left[\frac{D}{\rho}\left(\frac{3}{a^4}+\frac{2}{a^2b^2}+\frac{3}{b^4}\right)\right]$$

$\boldsymbol{f_n=124.56\ Hz}$

- **The Natural Frequency of Simply Supported Sandwich Plate with Including Shear Deformation**

Expression of the natural frequency of simply supported plate (including shear deformation)

$$\omega_{mn}=\pi^2\left[\left(\frac{mb}{a}\right)^2+n^2\right]\sqrt{\frac{D/\rho^*b^4(1-\nu^2)}{1+\pi^2\theta\left[\left(\frac{mb}{a}\right)^2+n^2\right]}}$$

Table 3: Natural Frequencies for Simply Supported Sandwich Plate for Various Modes

M	n	Mode Number	Frequency (Hz)
1	1	1	67.17
1	2	2	129.48
2	1	3	202.87
1	3	4	231.57
2	2	5	263.47

FINITE ELEMENT RESULTS FOR HONEYCOMB SANDWICH PANEL USING MSC NASTRAN/PATRAN (MODAL ANALYSIS)

Clamped Isotropic Sandwich Plate

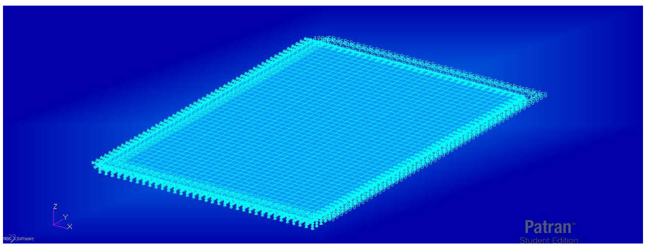

Figure 3: Clamped Isotropic Plate

The plate can be modeled in PATRAN by using the dimensions mentioned in Table 1. After that the plate surface can be meshed with quad elements by iso-mesh option. Hence 1700 quad elements could be created. The properties of the face sheet and core can be assigned accordingly which could be specified in the Table 2. The face sheet properties are for isotropic material and the elastic modulus is 70 $*10^3$ N/m^2, Poisson ratio 0.33 and density value is 2700 kg/m^3 assigned. The core also has a same isotropic material and elastic modulus is 1.004 N/m^2, Poisson ratio 0.33 and shear modulus is included which can be 1.4 E8 N/m^2. The face sheet 1, 2 and core thickness value can be entered and the orientation of the three material can entered as zero, after assigning the three materials as composite material. These three can be assigned to two dimensional material properties in which we considered these face sheet and core as a laminate structure.

In load and boundary conditions step the edge nodes are constrained by selecting the particular edge nodes. We consider the sandwich plate as clamped. Hence translation motion and rotational is arrested i.e. have entered as zero in all coordinate directions. And then the analysis can be done for extracting normal modes. Finally the natural frequencies are obtained for various mode numbers which is noted in Table 4 and the various modes shapes for clamped plate carried out and it has shown in Figure 4 to 9.

Table 4: Natural Frequencies for Clamped Plate

Mode Number	Frequency(Radians)	Frequency (Hz)
1	782.6	124.5
2	1207.7	192
3	1864.6	296.7
4	1912.3	304.36
5	2239	356.3

- **Mode Shape for the Clamped Sandwich Plate**

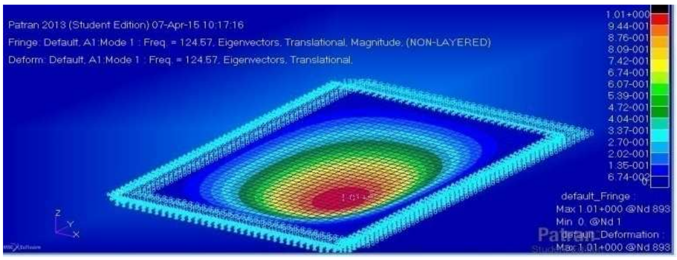

Figure 4: 1st Mode Shape for Clamped Sandwich Plate

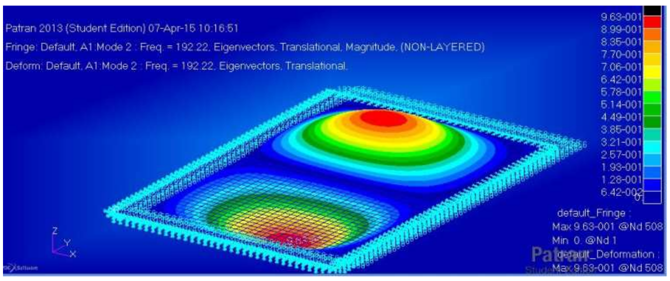

Figure 5: 2nd Mode Shape for Clamped Sandwich Plate

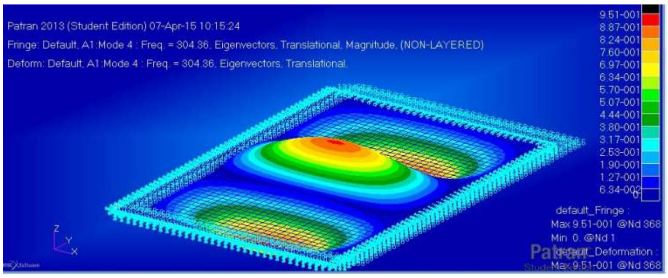

Figure 6: 3rd Mode Shape for Clamped Sandwich Plate

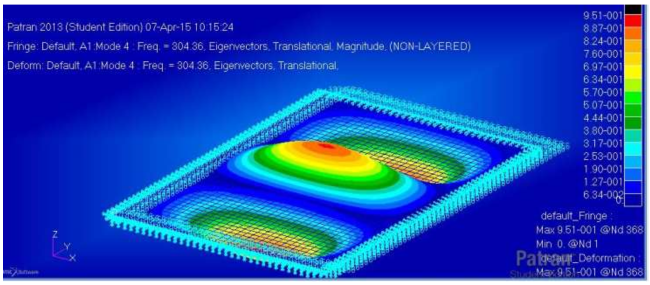

Figure 7: 4th mode Shape for Clamped Sandwich Plate

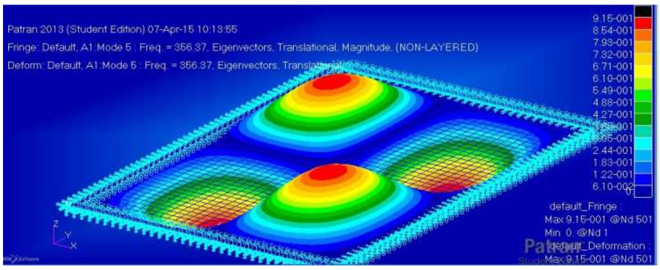

Figure 8: 5th Mode Shape for Clamped Sandwich Plate

- **Simply Supported Isotropic Sandwich Plate**

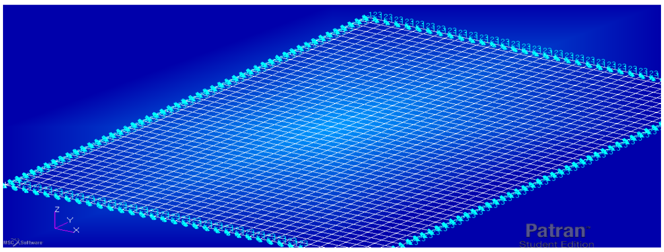

Figure 9: Finite Element Mesh on Simply Supported Plate

The plate can be modeled in PATRAN by using the dimensions denoted in Table 1. After that the plate surface can be meshed with quad elements by iso-mesh. From meshing 1700 quad elements could be created. The properties of the face sheet and core can be assigned accordingly. The face sheet properties are Isotropic material and the elastic modulus is 70 $*10^3$ N/m^2, Poisson ratio 0.33 and density value is 2700 kg/m^3 assigned which is denoted in Table 2. The core also has a same isotropic material and elastic modulus is 1.004 N/m^2, Poisson ratio 0.33 and shear modulus is included which can be 1.4 E8 N/m^2. The face sheet 1, 2 and core thickness value can be entered and the orientation of the three material can entered as zero after assigning the three materials as composite material. These can be assigned to two dimensional material properties in which we can consider these face sheet and core as a laminate structure.

In load and boundary conditions step the edge nodes are constrained by selecting the particular edge nodes. We considered the sandwich plate as simply supported. Hence translation motion is arrested i.e. simply entered as zero in all coordinate directions. And then the analysis can be done for extracting normal modes. Finally the natural frequencies are obtained for various mode numbers which is noted in Table 5 and the various mode shapes for simply supported plate carried out and it has shown in Figure 10 to 15.

Table 5: Natural Frequencies for Simply Supported Plate Various Modes

Mode Number	Frequency(Radians)	Frequency (Hz)
1	415	66
2	800.9	127
3	1269.8	202
4	1442	229.5
5	1633	259.9

Mode Shapes for the Simply Supported Sandwich Plate

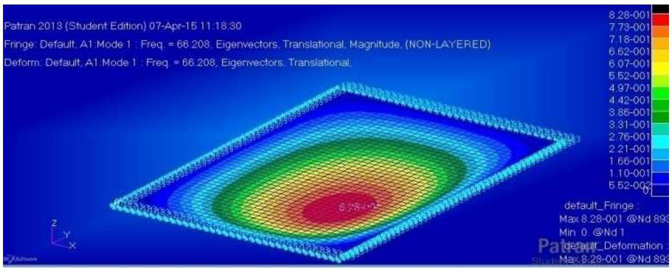

Figure 10: 1st Mode Shape for Simply Supported Sandwich Plate

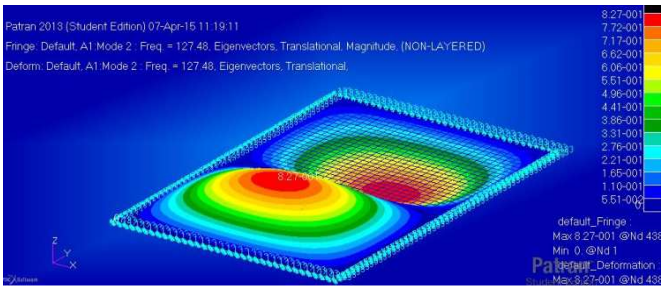

Figure 12: 2nd Mode Shape for Simply Supported Sandwich Plate

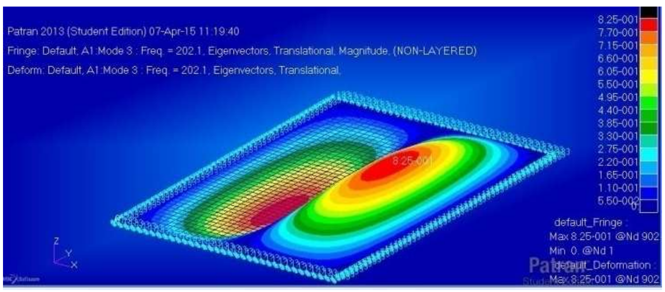

Figure 13: 3rd Mode Shape for Simply Supported Sandwich Plate

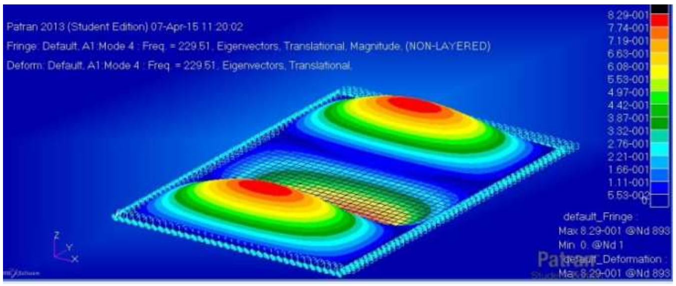

Figure 14: 4th Mode Shape for simply Supported Sandwich Plate

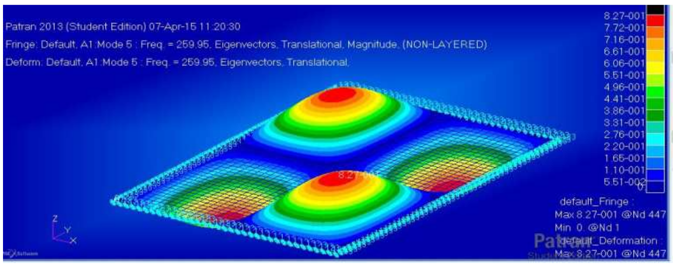

Figure 15: 5th Mode Shape for Simply Supported Sandwich Plate

TRANSIENT RESPONSE ANALYSIS

Based upon the dimensions plate can be drawn in PATRAN software. After that the plate surface could be meshed by the iso-mesher and the element shape is quad elements. Totally 1700 elements are created. The material properties would be assigned based upon above properties specifications noted in Table 2. And then the face sheet thickness and the core thickness assigned and also the orientation of the material properties assigned. These properties are assigned to the laminate material and finally two dimensional shell property created. In load and boundary conditions the edge nodes would be selected and plate translation and rotational parameters arrested (clamped support). After that these load and boundary condition assigned to load cases. The load case would be for time dependent parameter.

The spatial field would be created for twenty numbers of points and then the PCL expression can be noted for 10 milliseconds and the frequency of 50 hertz. Starting time would be 0.0 milliseconds and ending time would be 10 milliseconds it can be noted. Finally the force could be applied at a centre node of the plate and it would also be assigned to load cases.

In analysis solution type is transient response analysis and modal formulation. And subcases were created in which the subcase parameters the structural damping value 0.03 would be assigned for the zero frequency range to 1000 frequency range. The PATRAN solve these parameters and it can be analyzed in NASTRAN. Finally the graph can plotted against the time Vs force and Acceleration. Figure 18 shows that half sine response for force versus time and Figure 19 denoted that due to that force the acceleration response for the particular period of time interval.

- Force=1000 N
- Starting Time =0.0
- Ending Time=10 milliseconds
- Structural damping=0.03

- Frequency=50 Hz
- No of time steps =100
- Delta T=0.0001

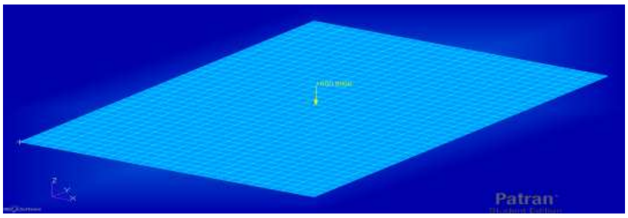

Figure 16: Finite Mesh on the Isotropic Plate

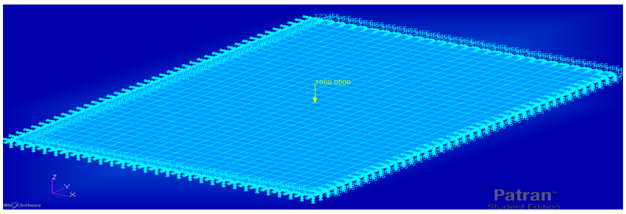

Figure 17: Forced Applied on the Center Node of the Plate

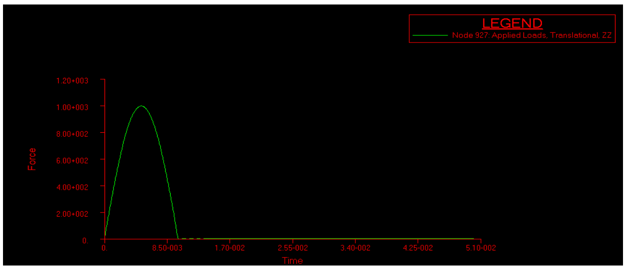

Figure 18: Force VS Time (Half Sine Pulse)

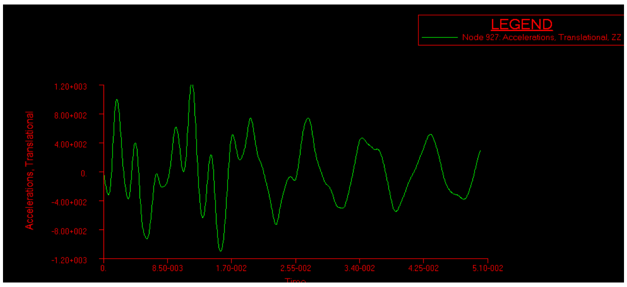

Figure 19: Accelartion vs Time

RESULTS AND DISCUSSIONS

Comparison of Analytical Results with FEM Results (MSC Natran/Patran)

The analytical results and FEM results are compared for clamped plate and simply supported isotropic plate.

Clamped Isotropic Plate Results

For the clamped Isotropic plate fundamental natural frequency (analytical solution) correctly match with the FEM results by using MSC NASTRAN/PATRAN.

Analytical solution for isotropic clamped plate (Fundamental natural frequency) =124.56 Hz

FEM results for clamped Isotropic plate =124 Hz

Simply Supported Isotropic Sandwich Plate Results

Table 6: Comparison of Analytical Results with FEM Results

Frequency(Hz)				
M	**N**	**Mode Number**	**Analytical Value(Isotropic)**	**FEM (Isotropic-Simply Supported)**
1	1	1	67.1667	66
1	2	2	129.48	127
2	1	3	202.87	201
1	3	4	231.572	228
2	2	5	263.47	259

The literatures, various case studies and parametric studies have been done. From these the specific problem could be identified. According to the problem definition, the spacecraft structure experiences various kinds of loads such as vibration, shock loads, acoustic loads. Clamped isotropic plate and simply supported plate have been modeled and analyzed for specific dimensions, properties in MSC NASTRAN/PATRAN. From the analysis natural frequencies and modes shapes are calculated. The natural frequencies were varying for the different number of elements. Hence the natural frequencies for various numbers of elements compared and the standard number of elements case noticed. Hence, the natural frequencies for standard number of elements are compared with the analytical solutions. From these comparisons the fundamental natural frequency for clamped plate very well matches with the analytical solutions. And the simply supported case also the natural frequencies are appropriately matched with the analytical solutions. The mode shapes were plotted for the particular mode number.

Due to the pyroshock or pyrotechnic the sudden shock load will occur on the spacecraft structure. These shock load will occur for certain period of the time. Hence the transient response analysis has done for 10 milliseconds and output results has been plotted and noticed.

CONCLUSIONS

Vibration studies of honeycomb sandwich panel for spacecraft applications are carried out. A typical honeycomb panel is considered for analysis. Modal analysis and transient response analysis are carried out for the honeycomb panel. Natural frequencies of the panel for simply supported and clamped boundary conditions are determined analytically as well as by FEM simulations. The FEM simulations are carried out using MSC PATRAN/NASTRAN. The analytical and FEM results are matching well. The natural frequency of the panel should be uncoupled from the launch vehicle and the spacecraft natural frequency. The natural frequency (stiffness requirement) of the panel should be greater than 40 Hz so that it is uncoupled from the spacecraft fundamental natural frequencies which are in the range of 12-15 Hz. The fundamental natural frequencies of the launch vehicle are still lower in the range of less than 5 Hz. It is observed from the analysis that the honeycomb panel is meeting the natural frequency requirement.

Transient response of a typical honeycomb panel is determined for a pyroshock device. The transient force due to the pyroshock device is simulated in the form of a half sine pulse and the acceleration response of the panel is determined using FEM. The acceleration response should not exceed the tested vibration levels of the equipment placed on the panel. It is observed from the analysis that the transient response of the panel meets this requirement.

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